Bioacoustic Absorption Spectroscopy

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LONG TERM GOAL

Demonstrate the potential of bioacoustic absorption spectroscopy for tomographic mapping of the bioacoustic parameters of fish with swim bladders in shallow water.

OBJECTIVES

Develop an acoustic propagation model that accounts for bioacoustic absorptivity due to fish with swim bladders on transmission loss as a function of frequency over the frequency range 0.5-5.0 kHz in shallow water. Develop a bioacoustic model that accounts for the resonance frequencies of absorption lines, which are due to dispersed pelagic fish, and schools of pelagic fish with swim bladders. Develop a model of the seasonal variability of resonance frequencies. Demonstrate consistency between absorptivity and echo sounder based estimates of number densities.

APPROACH

Invert bioacoustic parameters from transmission loss data recorded during Modal Lion, by matching theoretical computations with data. Demonstrate consistency between absorptivity and echo sounder based estimates of number densities of sardines in the Gulf of Lion. Develop an analytical model to account for the frequencies of measured absorption lines by extending a previously published theory of the resonance frequency of "bubble clouds". Design broadband, long term, autonomous sources and receivers, that will permit long term monitoring of bioacoustic parameters. Conduct new bioacoustic absorptivity experiments in littoral seas in co-operation with fisheries biologists. The first planned experiment will be in the seas off California in co-operation with the Southwest Fisheries Science Center of NOAA's National Marine Fisheries Service. These experiments will be designed to investigate the "signatures" of the two major classes of fish with swim bladders physotomes (volumes vary inversely with pressure) and physoclists (volumes are independent of pressure) in time frequency space. Simulate effects of absorptivity on transmission loss vs. time and frequency of physostomes and physoclists. Apply model to new and previously published bioacoustic absorptivity measurements, derive bioacoustic parameters, and demonstrate consistency with biological measurements.

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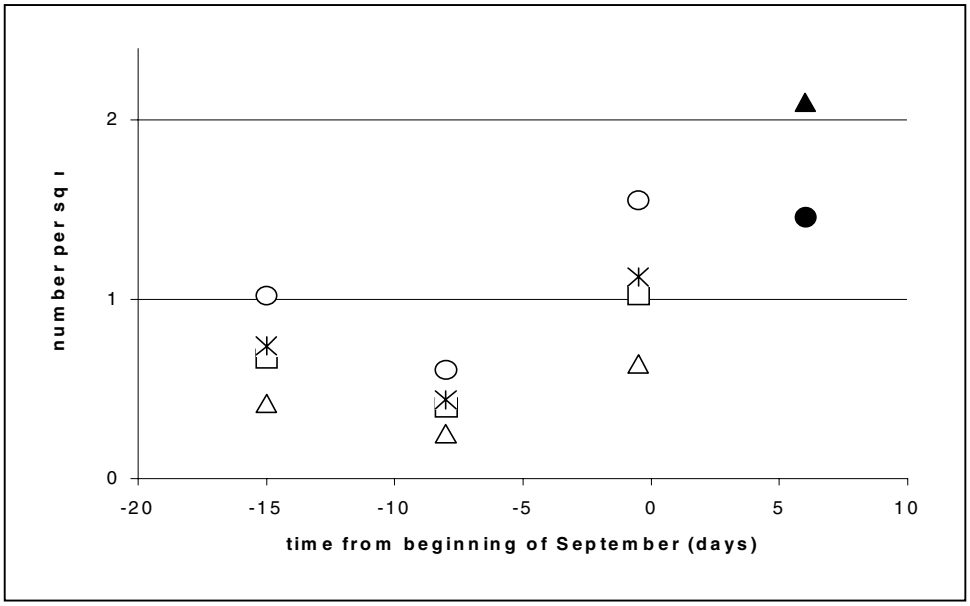
WORK COMPLETED

During FY 99 I completed documentation of research, which resulted in a paper, which was titled “Estimation of number densities of fish from resonance absorptivity and echo sounder data”. This paper was submitted to The International Council for Exploration of the Seas (ICES) Journal of Marine Science. This paper will be the first to provide a quantitative comparison of number densities derived from absorptivity and echo sounder data. It includes a critical analysis of the classification of spectral absorption lines with the constraint, that classifications must be consistent with echo sounder based estimates of number densities. During FY 99 I also completed analysis of previously reported measures of the seasonal variability of resonance frequencies (Ching and Weston, 1971).

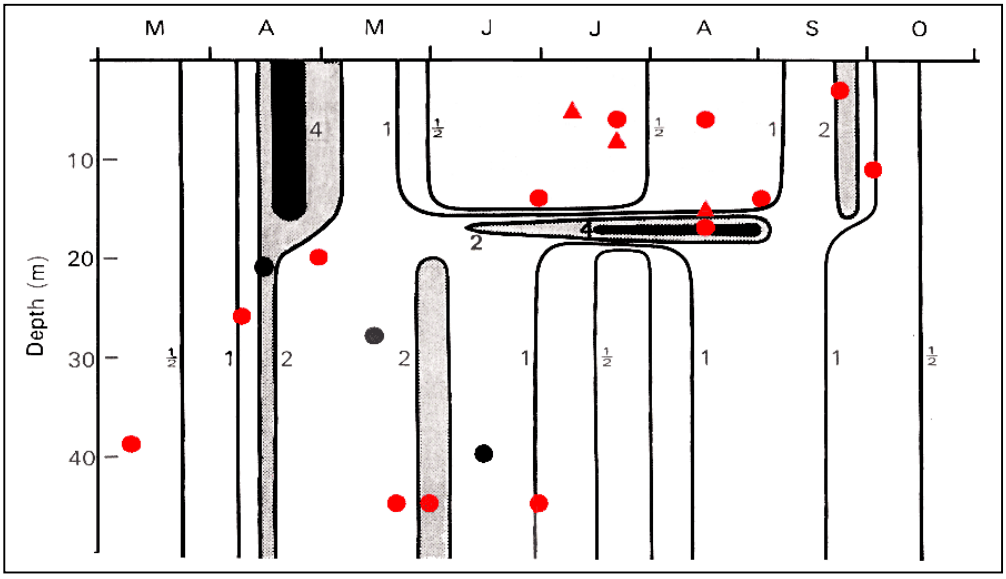
RESULTS

Measured resonance frequencies of absorption lines, which were attributed to adult (~ 1.3 khz) and juvenile (~ 3.9 kHz) sardines, were demonstrated to be consistent with calculated frequencies, which were based on measurements of the dimensions of swim bladders of adult and juvenile sardines. These results suggest that bioacoustic absorption spectroscopy measurements permit isolation of juvenile from adult pelagic fish. The pressure dependence of measured resonance frequencies was shown to be consistent with Boyle’s law. Systematic changes in resonance frequency were temporally coincident with echo sounder measurements of vertical migrations of dispersed sardines at twilight. These results were documented in a paper, which was published in the Journal of the Acoustical Society, and in another paper, which will be published in a peer- reviewed book in 1999.



1. Number densities (number per square meter) of sardines vs. time (days).

Figure 1 shows estimated number densities of sardines per square meter, which were derived from absorptivity and echo sounder measurements vs. time. The absorptivity based estimates are based on the assumptions that the absorption line at 1.3 kHz was due to sardines (▲), and sardines and anchovies in accord with the measured ratio of number densities (●).The initial echo sounder based estimates, which were provided by my collaborator (Dr. Liorzou of Ifremer, Sete, France), were based on a "universal", pressure independent equation of target strength, and disregarded potential sources of bias due to attenuation by near surface bubbles, and avoidance. This figure shows echo sounder based estimates, which assume a "universal" pressure independent value of target strength (△), and corrections for the pressure dependence of target strength of sardines (□), and avoidance (✻), and attenuation due to near surface bubbles (O). The *corrected* absorptivity based estimate, 1.5 / m^2, and the average *corrected* echo sounder based estimate, 1.1 / m^2, are in good agreement. These results suggest the possibility of estimating number densities from broadband tomographic transmission loss measurements over large areas.



2. Depths of sardines and contours of phytoplankton concentrations vs. time (months).

The theoretical equation of the resonance frequency of dispersed sardines, which is a function of the effective radius and eccentricity of the swim bladder and the pressure (Diachok, 1999), was applied to Ching and Weston's (1971) measurements of the seasonal variability of resonance frequencies of absorption lines due to sardines. Results of this analysis suggest that sardines occupy depths at night, which approximately coincide with the depths of phytoplankton maxima. Figure 2 shows contours of phytoplankton concentrations vs. depth (in meters) between March (M) and October (O) at a nearby site, due to Holligan and Harbor, (1977). Similar patterns of phytoplankton concentrations vs. depth and time of year have been observed elsewhere (Flagg et al., 1994). Also shown in this figure are echo sounder based measurements of the depths of adult sardines (●) at a nearby site, and absorptivity based estimates of the depths of adult

(●) and juvenile (▲) sardines. This result is the first step toward development of a model that will predict the seasonal variability of resonance frequencies of pelagic fish in littoral seas. Documentation of this result is in progress.

IMPACT / APPLICATIONS

Naval significance: This research suggests that the detection range of naval tactical sonars may be significantly reduced when operating in littoral environments dominated by pelagic fish with swim bladders. Strategic areas where fish concentrations may be particularly high include the littoral seas off the coasts of the United States, Europe and China. Since the Q of the resonance is about 2, combatants with sonars that operate at different frequencies may find themselves in situations, where one may have a long detection range (e.g. at 3 kHz), whereas the other may have a short detection range (e.g. at 5 kHz) in the same environment at the same time. Effects due to bioacoustic absorptivity should be incorporated into formulating environmental adaptation strategies for tactical sonars.

Fisheries applications: These results suggest that bioacoustic absorptivity can be used to estimate number density (biomass) of juvenile and adult pelagic fish with swim bladders in littoral environments.

TRANSITIONS

Naval Research Laboratory (NRL) management has decided to support a three year 6.2 research program to conduct experimental and theoretical investigations on the effects of bioacoustic absorptivity on transmission loss in littoral seas starting in FY 00.

RELATED PROJECTS

NRL: 6.2 research program, “Effects of bioacoustic absorptivity on transmission loss in littoral environments”.

ONR: 6.1 ASIAEX Project.

Ifremer, Sete, France: biological sampling program.

Saclant Undersea Research Centre: theoretical modeling.

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PATENTS

The Naval Research Laboratory has decided to apply for an international patent on my design of low cost, ultra-wide bandwidth, light weight, autonomous source and receiver arrays, which were designed to permit bioacoustic absorption spectroscopy measurements in littoral seas between a fixed source and multiple widely spaced fixed receivers.